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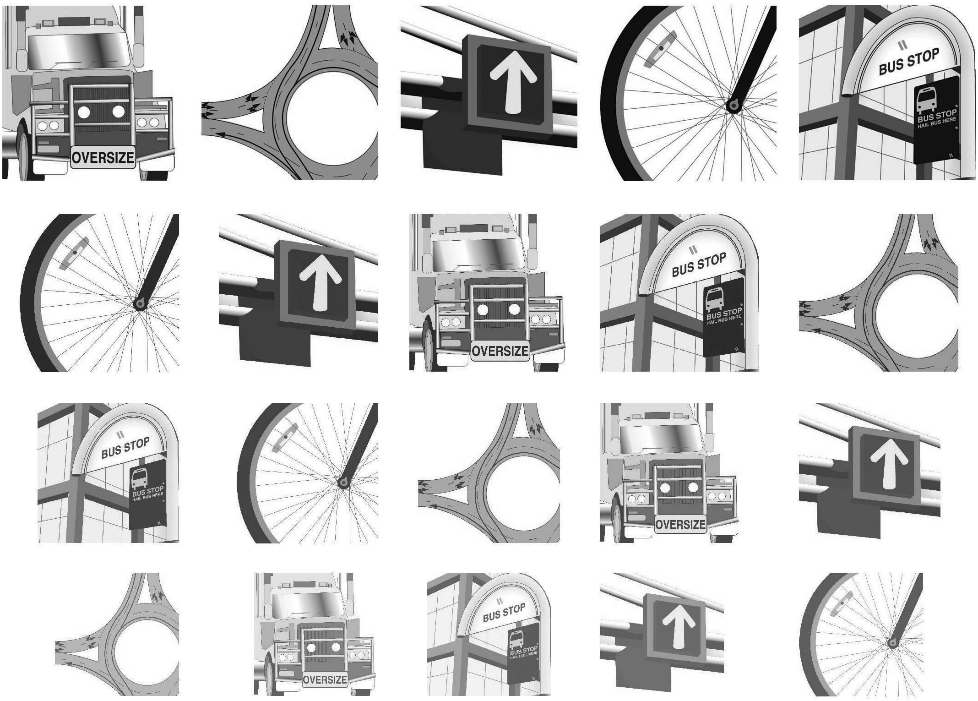
Priority Treatment:
Juggling Competing Demands



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Priority Treatment:
Juggling Competing Demands

Coordinating for priority on urban arterial freight routes

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ABSTRACT

Demands of freight and passenger traffic are often considered to be in competition, particularly on designated urban freight routes that use major arterial signalised traffic corridors. A microsimulation model of an urban traffic corridor in Brisbane was developed in order for corridor performance to be evaluated for alternative priority treatments. The model was calibrated with GPS travel time and trajectory data for a range of vehicle classes typical of those found on Australian urban freight routes. Intersection status was recorded simultaneously by the STREAMS traffic management system, enabling the progression of different vehicle classes to be validated under existing signal timing plans.

The model can be applied to the optimisation of corridor signal timings. Unlike other models, it was possible to define vehicle-specific performance measures, such as delay, number of stops, and a combination of these. The model can be used to find the best combination of signal timings to favour the progression of particular vehicle classes, such as large freight vehicles. The effects on other vehicle classes can be noted; finding that, although being suboptimal for other classes, it may be possible to achieve some overall gains in traffic efficiency.

1 Introduction

The limited road space in Australia's urban areas is being called upon to service increasing volumes of both private and commercial traffic. These two are often considered to be in competition, with high-capacity urban corridors frequently also serving as major freight routes.

An increasing disparity between vehicle types is also evident. Large freight vehicles (LFVs), such as B-doubles, are becoming more popular with operators due, in part, to their accessibility to urban areas. The Survey of Motor Vehicle Use (ABS 1972-2004) has recorded a steady increase in the use of B-doubles, from 14 per cent of total freight tonne-kilometres carried in 1998 to 24 per cent in 2003. This accounted for almost all of the increase in road freight carried over this period.

Despite the fact that fewer vehicles are required for a given freight task (Haldane and Bunker 2002), individual vehicles have a greater effect on corridor capacity and the delay experience by all vehicles on the corridor. It is this effect of individual vehicle on the surrounding traffic that is most noticeable by the motoring public.

This paper reports on an investigation being undertaken by Queensland University of Technology into the effects of large freight vehicles on urban traffic corridor performance as part of an Australian Research Council Linkages Grant, with Queensland Department of Main Roads as the industry partner. The project aims to:

- improve the management and operation of LFVs in urban centres
- gain a better understanding of how LFVs interact with other traffic
- incorporate that understanding into an analytical assessment tool.

2 Background

2.1 Competing demands

The prevalence of large freight vehicles on urban traffic corridors is a common concern in most Australian capital cities and regional towns. Sullivan (2003) identified Yarraville in Victoria, Fremantle in Western Australia, the Sydney port area and the Brisbane Urban Corridor (BUC) as areas where increasing road freight traffic is causing concerns in urban and residential areas. A community consultation report (Taylor *et al.* 2003) found issues related to trucks on the BUC to be of the highest priority amongst hundreds of concerns from community members.

> Issues about trucks reflected the community's concerns with the increasing number of trucks using BUC (especially non-local trucks), noise (specifically from trucks), truck driver behaviour and the types of goods being carried.

Among the recommendations of that study was to encourage trucks to use an alternate route by removing night-time tolls on a nearby motorway for trucks having three or more axles. This has since been introduced on a trial basis, with tolls still payable by trucks during day time.

Alternative routes to physically separate different vehicles types are often not available, or are not viable. Measures must then be considered to manage the competing demands on the one corridor.

2.2 Vehicle characteristics

Apart from the obviously greater length of LFVs, the greater mass and lower power-to-mass ratio gives a lower acceleration rate and greater sensitivity to grade compared to passenger cars. Although LFVs may be heavier than general-access articulated trucks, the acceleration rates may not be significantly different since their prime movers are generally more modern and have somewhat greater power.

When starting from rest, such as from a signalised intersection, heavy trucks have a greater start response time (average of 3.25 seconds according to Di Cristoforo *et al.* 2004) compared to passenger cars (average of 1.15 seconds using data in Akçelik *et al.* 1999).

All of these factors combine to greatly increase the time taken to clear a fixed obstacle, such as an intersection or railway level crossing.

Braking capabilities of heavy vehicles are regulated by Australian Design Rules, which prescribe emergency stopping distances which are compatible with those of the surrounding traffic. In-service braking rates may be lower than for passenger cars, due to a greater sight distance offered from a truck cabin. Actions in the dilemma zone when approaching a changing traffic signal may be different for a heavy vehicle, partly due to the unpleasant prospect of having to regain lost momentum (Ramsay 1998).

2.3 Strategies

Several strategic measures to manage trucks in urban areas have been identified (Ogden 1999). Several of these, such as route and area bans or geometric constraints, act to disadvantage freight movements on a particular route or location. This may move the problem elsewhere, require enforcement, and impose extra costs to operators (and ultimately consumers, affecting the economy).

Other measures were proposed by Ogden to manage, rather than eliminate, the problem of trucks in urban areas. By accepting that a range of vehicle types must continue to be catered for, strategies can be developed to reduce overall transport costs without excessively disadvantaging any particular group or vehicle type.

The allocation of lanes for the exclusive use of trucks may reduce delay. Depending on congestion levels, an improved level of service may be experienced by cars, trucks, or both.

2.3.1 Signal settings

Settings at individual signalised intersections may also be able to be managed to cater explicitly for the needs of trucks. Ogden (1999) included the following in these measures:

- Longer clearance times or all-red times (to allow for lower speed and poorer braking)
- Dynamic truck detection and green phase extension so that signals do not turn yellow as a truck is approaching
- Longer minimum phase times (to allow for slower acceleration)
- Adjustment of the gap and waste timers to allow for longer headways between vehicles (caused by slower truck acceleration)
- Turning phase warrants taking particular account of truck turning volumes
- Adjustment of passenger car equivalent factors if there is a high proportion of articulated trucks

In the general case of cars and trucks having equal access to all lanes, these strategies may offer advantages to cars as well as to trucks, by removing the bottleneck effect of slow moving trucks at intersections. However, if trucks were restricted to specific lanes, these measures would be likely to disadvantage cars.

2.3.2 Linked signals

Ogden mentions that trucks can be disadvantaged by linked signals if the offsets between signals are based on car travel times, which slower-accelerating trucks cannot match. In the worst case, these slower vehicles may face a ‘red wave’ rather than a ‘green wave’, arriving at every signal just as it turns red. Following vehicles are also disadvantaged.

Signal linking strategies which are mentioned include:

- Linking based on truck speeds
- Link high volume truck turning movements
- Link on the basis of counter-peak travel times when congestion in the peak direction precludes linking
- Minimise the density of signals (signals per kilometre)
- Reduce cycle times as far as possible

Although many of the measures mentioned above offer advantages to all road users, others seek overall gains in traffic efficiency at the expense of particular user groups. These disadvantages could be reduced if priority measures were able to be implemented only when required.

2.3.3 Vehicle detection

Detection of priority vehicles, and implementation of associated favourable traffic strategies, is already widely in use in Australia and elsewhere in the world. A review of available schemes (Fox *et al.* 1998) identified Brisbane's RAPID bus priority system and SCATS' ability to prioritise trams in Melbourne amongst numerous successful public transport priority systems. Some schemes can provide for emergency vehicle priority, relying on vehicle-mounted transponders.

Fox notes that BLISS has two further 'selective vehicle priority' applications: the ability to handle long, slow-moving vehicles which require longer than the normally-available green time to cross an intersection; and the handling of slow-moving convoys of vehicles (eg for international dignitaries). The former requires vehicle identification tags and the latter involves special signal timing plans.

Long, slow-moving vehicles could also be handled by existing vehicle detection methods. In-ground inductive loop detectors can differentiate between a long, slow-moving vehicle (which may require priority action), and a long-fast-moving vehicle (which would not benefit as much from it).

Fox *et al.* identified several strategies for handling individual priority vehicles once detected:

- **Extensions**, where a green is extended to allow the priority vehicle through the junction
- **Recalls**, where a movement giving green to the priority vehicle is brought in early
- **Queue jumping**, where a special movement which gives priority vehicles a chance to start ahead of other traffic is triggered
- **Queue management**, where queues of traffic are cleared to allow the priority vehicle a clear run through a junction
- **Triggering green waves**, where a progression through a series of junctions is triggered by the arrival of a priority vehicle.

3 Research Method

The research being undertaken aims to investigate the effectiveness of various strategies for managing freight vehicles in urban corridors. There are five stages to the project:

- **Review** of existing investigations of freight vehicle impacts on corridor performance; identify suitable tools/models, or requirements for them, for conducting the required investigations
- **Develop** (or adapt) a model of multi-class traffic flow in an urban traffic corridor to enable investigations to be conducted
- C**ollect data** from a representative corridor in order to calibrate and validate the model
- **Calibrate** and **validate** the model
- **Implement** the model to examine the effectiveness of various policy-directed scenarios

3.1 Review

A range of existing traffic models were reviewed for their suitability for use or adaptation in the existing project. As a minimum, candidate models were required to be able to represent traffic flowing along a multi-lane traffic corridor consisting of links between coordinated signalised intersections. The following types of models were considered:

- **Deterministic** macroscopic models (eg TRANSYT): intended for corridor timing analysis and design, handles packets of vehicles, and hence is unable to effectively account for different vehicle types
- **Discrete-space** microscopic models (eg Cellular Automata models): efficient simulation algorithms, doesn't track individual vehicles or cater for different vehicle characteristics
- **Discrete-event** microscopic models: efficient, able to handle different vehicle types, but often having difficulty managing interactions with surrounding vehicles
- **Discrete-time** microscopic models (eg Paramics, AIMSUN): well-developed software, offering many calibration parameters. Vehicle motion models could be improved
- **Discrete-vehicle** models: very accurate characterisation of vehicle dynamics in the absence of other traffic. Possibly too detailed for inclusion into a traffic-based model due to numerous vehicle-specific parameters having to be calibrated

The review identified a need for a simplified discrete time microsimulation model which accurately models the discrete motion of individual vehicles (particularly of heavy vehicles).

3.2 Model Development

A discrete-time microsimulation model was developed, drawing on many of the principles used by other models in the review. Figure 1 is a simplified flow chart for the model, showing that it runs through each vehicle at each time-step in the simulation. The vehicle's acceleration is based on the current speed, grade, speed limit, neighbouring vehicles and intersections, ensuring that the vehicle does not exceed its capabilities, remains below the speed limit, does not collide with the leading vehicle, and stops when required at signalised intersections. This acceleration is then used to predict the speed and position at the next time step. Intersection status is updated at each time step, with each vehicle 'knowing' the next intersection and the surrounding vehicles.

The model is currently limited to simulation of a single direction multi-lane corridor containing several intersections. Many additional features offered by commercial microsimulation software packages were not necessary for the current project, and hence were not implemented in the model.

The ability of vehicles to change lanes is included in the model, with vehicles changing into an adjacent lane if there is a perceived speed advantage and a suitable gap exists. Unlike other models, the decision to change lanes is influenced by the type of vehicle being followed – a vehicle following a larger vehicle has a greater desire to change lanes, even more so if the lead vehicle is stopping at a signalised intersection.

Figure 2 shows an example simulation of traffic on an urban arterial traffic corridor. The program overlays the trajectories of all vehicles on the corridor signal timing chart. This simulation demonstrates the 'red wave' mentioned by Ogden (1999) and Ramsay (1998), which is experienced by a slowly-accelerating vehicle arriving at each intersection just as it turns red. Lane-changing has been disabled for this particular simulation – normally, following vehicles would have opportunities to overtake the slower vehicle and the queue build-up would not be as significant.

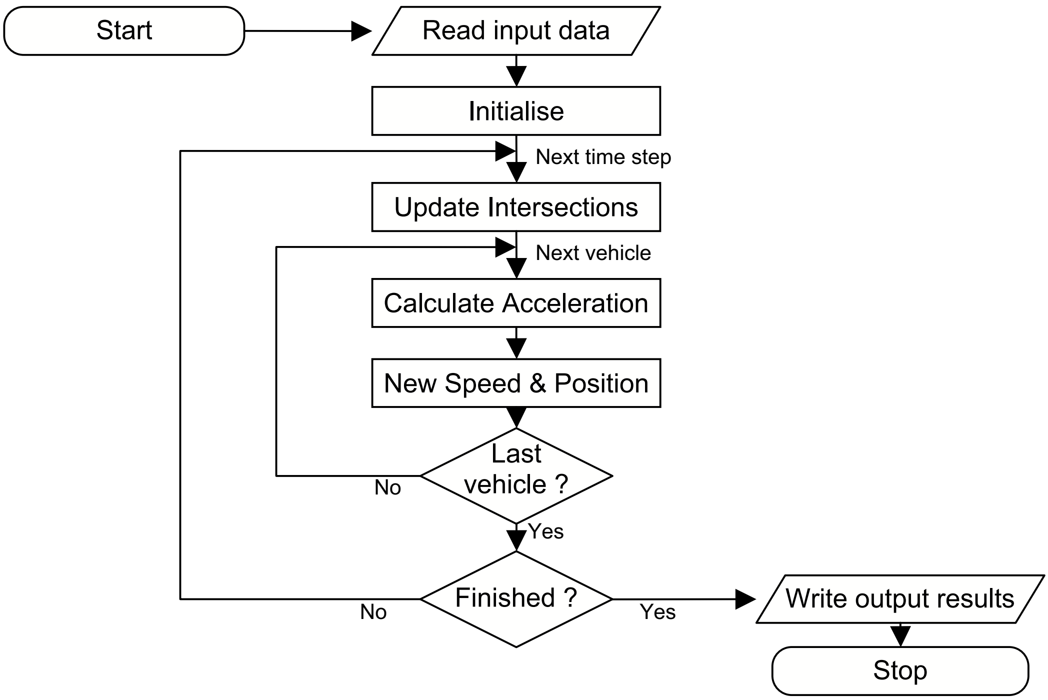

Figure 1 – Simplified corridor-level microsimulation model flow chart

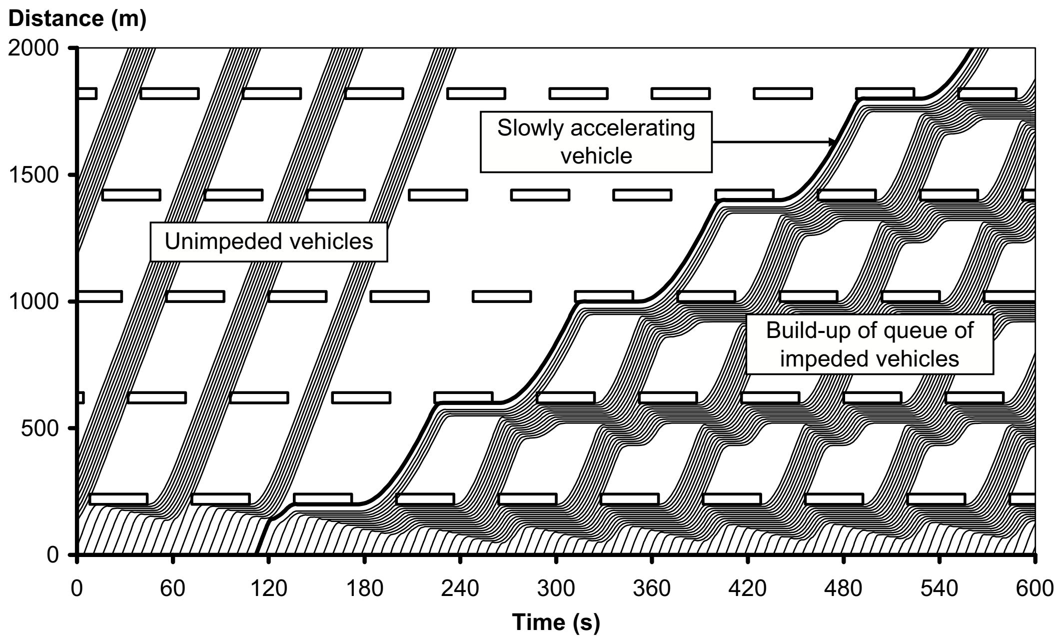

Figure 2 – 'Red Wave' experienced by a slowly-accelerating vehicle, acting as a moving bottleneck

3.3 Data Collection

The model was calibrated using data obtained from the Brisbane Urban Corridor, an eleven-kilometre arterial road corridor with numerous closely-spaced signalised intersections running through varying terrain. The corridor provides access between two motorways and carries a large number of freight vehicles past residential and commercial developments. Also, being within close proximity to Brisbane, it was seen as the most suitable corridor to provide data for the model.

Data was collected in two separate, but concurrent experiments:

- **Traffic flow survey:** giving traffic volumes, compositions, and headway distributions at one location on the corridor
- **Chase car survey**: giving travel time / speed as well as in-service vehicle characteristics

Together with generic data from other sources, these experiments provided data to separately calibrate the inputs to the model and to validate the model outputs.

The chase car survey used a GPS receiver to record instantaneous position and speed at one-second intervals. This method was considered safer, more accurate and more efficient than having the driver or a passenger manually record the data. The recorded data had sufficient resolution to identify when and where the subject vehicle stopped, and even the rate at which it accelerated or decelerated. The alternative of fitting instrumentation directly to a range of subject vehicles would give a more direct measure of its motion; however it would require considerably more effort per vehicle, allowing for fewer runs being conducted in the same time, and the driver(s) would be aware of the presence of the experiment.

A large number of vehicles were followed over the corridor, each vehicle being identified as either a passenger car, 4WD or light commercial vehicle, rigid truck, articulated truck, or B-double. Travel times of different vehicle types were not significantly different, compared to the variation in travel times throughout the day. Differences in vehicle behaviour were evident during intersection queue departure amongst the vehicle types.

The status of the signalised intersections along the corridor was recorded using the STREAMS traffic management system at the same time as the chase car survey. It was possible to overlay the GPS-recorded vehicle trajectory on the corridor signal timing diagram.

3.4 Calibration and Validation

Representative acceleration and braking profiles were determined for each vehicle type when vehicles stopped and started at intersections using the chase car survey data. A relatively simple model of acceleration decreasing linearly with increasing vehicle speed gave a good match to the data. Some variation was found in performance within the same vehicle type, particularly for the larger vehicles which have a greater difference between laden and unladen mass.

The model is validated by running simulations with the upstream arrival flow profile and the intersection timing plans set to be the same as those recorded on the BUC. Predicted travel times and stop rates can be compared to those recorded by the GPS unit used in the chase car survey.

4 Applications

The purpose of the model is to examine the effectiveness of various priority-related policy strategies upon the performance of a signalised traffic corridor. Sensitivity studies can be conducted to determine the effects that various input parameters have on output measures, or combinations of measures. These include:

- **Primary measures**, such as average travel time (or travel speed) and number of stops over the corridor for a range of vehicle types
- **Secondary measures**, such as fuel consumption, emissions, noise
- **Tertiary measures**, including expected vehicle operating costs and travel costs

In doing so, the model can be used to provide data for a ‘Triple Bottom Line’ analysis of corridor-level traffic policy strategies – analysing the social, environmental and economic impacts.

The following example scenarios are able to be investigated in greater detail, with analyses to be reported in a forthcoming paper:

4.1 Signalised corridor offset specification

The offsets between signals in a coordinated corridor have a large influence on the progression of traffic on the corridor. As shown in Figure 2, allowing insufficient time for slower vehicles to progress through the corridor may result in moving bottlenecks, affecting all traffic on the corridor. Offsets can be specified to:

- match the desired travel speed of the most common vehicle type, results in slower vehicles acting as moving bottlenecks and disadvantaging vehicles trapped behind them
- match the desired travel speed of slower vehicles, favouring their progression but giving a slower, less variable flow
- a global optimum lying somewhere between these, likely being dependent on the number of overtaking opportunities

The model may be used to find this optimum by conducting repeated simulations with different offsets. The simulation giving the best overall performance (based on a combination of travel times, stop rates, and other measures mentioned above) would have the optimum offsets. Other software (eg TRANSYT) is available to optimise signal offsets on a corridor, or even an entire network, however they do not handle different vehicle classes in as much detail as the current model does.

Traffic in the opposing direction must also be considered in the optimisation of corridor signal timings. When congestion levels are such that little advantage can be gained from coordination in the peak traffic flow direction, benefits for the reverse direction may be able to be found.

4.2 Minimum green time selection

Occasionally, the minimum green time (generally based on pedestrian crossing times) may be insufficient for a long, slowly accelerating vehicle to clear an intersection when starting at the head of the queue (particularly for intersections on grade). Related to this, specification of green time and offsets at closely-spaced intersections may offer progression advantages to these vehicles.

A relatively simple formula can be derived to calculate the minimum required bandwidth through single or multiple intersections, based on the width of the intersection (or distance between intersections in the latter case), design speed, minimum expected acceleration rate, and grade. The microsimulation model would be able to verify whether this bandwidth specification provides for progression of all vehicle types, including the slowest-accelerating ones.

4.3 Cycle time selection

Extending the green time reduces the capacity on opposing movements, unless the cycle time is also increased. Shorter cycle times in theory provide lesser overall delay, but this is countered by the proportion of inter-green time being greater. Despite Ogden's favouring of short cycle times for heavy vehicles, longer cycle times may give fewer stops per intersection, reducing the associated driveline stress, noise, emissions and fuel consumption of heavy vehicles.

The model can be used to investigate the effect of cycle length on delay and other measures for a range of vehicle types.

4.4 Gap timer selection

The large headways in front of a slowly-accelerating or slowly-moving vehicle may cause vehicle-actuated signals to gap-out, or sense that there is insufficient flow to continue the movement. A longer gap timer setting may reduce this likelihood, and of the signal changing to red as the heavy vehicle reaches it. An appropriate strategy may be to hold the movement until the detected slowly-accelerating vehicle had passed.

The gap timer setting within the model can be varied to determine its effect on intersection performance with different vehicle types present.

4.5 Heavy vehicle detection

Heavy vehicles could be detected using specialised tags or with existing detection technologies. Existing inductive loop detectors (located 33-metres before the stop-line) would need to be supplemented with advance upstream detectors. Potential strategies for assisting the progression of priority vehicles are covered earlier in this report. Giving priority to heavy vehicles may be particularly beneficial in off-peak conditions, potentially offering a reduction of the noise associated with braking and accelerating heavy vehicles at night.

The model can be use to determine appropriate locations for advance detectors in order for priority strategies to be effective.

4.6 Lane utilisation / restrictions

Capacity may be improved by restricting particular vehicle types to certain lanes, offering particular advantages to passenger cars. Road-space utilisation could also be improved, since there would be no large headway in front of a slowly-accelerating vehicle which is behind another slowly-accelerating vehicle.

Exclusive use of a lane by a certain vehicle type would only be warranted if there are sufficient numbers of that vehicle type. Restrictions of particular vehicle type to specific lane(s) would not necessarily prevent other vehicle type from using that lane.

The model is able to restrict particular vehicle types to specific lanes, enabling comparison of different lane utilisation strategies.

4.7 Freight vehicle-mode change

Despite the emphasis being on the impacts of individual vehicles, it should be recognised that the choice of vehicle used to carry a specified freight volume has a large influence on the number of freight vehicles required. Performance measures need to be evaluated in terms of both fixed freight volume and fixed vehicle numbers.

The arrival flow profile used in the model may be varied to investigate freight-vehicle-mode sensitivities. For example, every two B-doubles could be replaced with three articulated trucks to maintain a fixed freight volume.

5 Conclusion

We have outlined a research project which is studying the impacts of large freight vehicles on urban traffic corridor performance. A model has been developed which is able to quantify the social, environmental and economic implications of various policy-related strategies – providing output information that may be of use in a triple-bottom-line analysis. Several potential strategies have been discussed, with the analysis results to be the subject of a forthcoming paper.

The competing demands of private and commercial traffic may be managed by offering a measure of priority to particular vehicles, seeking overall gains in traffic efficiency despite possible increased cost to certain vehicles. Overall gains in traffic efficiency may be realised through the elimination or reduction of moving bottlenecks – all vehicles being assisted by strategies which keep freight vehicles moving along a corridor.

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